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(पहला पुनरीक्षण)

Indian Standard

SEMICONDUCTOR OPTOELECTRONIC DEVICES FOR FIBRE OPTIC SYSTEM APPLICATIONS

PART 2 MEASURING METHODS

(First Revision)

ICS 33.080.01; 31.260; 31.180.01

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NEW DELHI 110002

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Fibre Optics, Fibres, Cables and Devices Sectional Committee, LITD 11

NATIONAL FOREWORD

This Indian Standard (Part 2) (First Revision) which is identical with IEC 62007-2 : 2009 'Semiconductor optoelectronic devices for fibre optic system applications — Part 2: Measuring methods' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Fibre Optics, Fibres, Cables and Devices Sectional Committee and approval of the Electronics and Information Technology Division Council.

This standard was originally published in 2001 which was identical with IEC 62007-2 : 1997 and has now been revised to align it with the latest version of IEC 62007-2 : 2009.

Semiconductor optical signal transmitters and receivers play important roles in optical information networks. This standard covers the measurement procedures for their optical and electrical properties that are intended for digital communication systems. These properties are essential to specify their performance.

The text of IEC Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.

b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards which are to be substituted in their respective places are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
IEC 60793-1-1 : 2008 Optical fibres — Part 1-1: Measurement methods and test procedures — General and guidance	IS 15056 (Part 1/Sec 1) : 2012 Optical fibres: Part 1 Measurement methods and test procedures, Section 1 General and guidance (*first revision*)	Identical
IEC 60793-1-20 : 2001Optical fibres — Part 1-20 : Measurement methods and test procedures — Fibres geometry	IS/IEC 60793-1-20 : 2001 Optical fibres: Part 1 Measurement methods and test procedures, Section 20 Fibres geometry	do
IEC 60793-1-21 : 2001 Optical fibres — Part 1-21: Measurement methods and test procedures — Coating geometry	IS/IEC 60793-1-21 : 2001 Optical fibres: Part 1 Measurement methods and test procedures, Section 21 Coating geometry	do
IEC 60794-1-1 : 1999 Optical fibre cables — Part 1-1: Generic specification — General	IS 13882 (Part 1/Sec 1) : 2001 Optical fibre cables: Part 1 Generic specification, Section 1 General (*first revision*)	do
IEC 60874-1 : 1993 Connector for optical fibres and cables — Part 1: Generic specification	IS/IEC QC 21000 : 1994 Connector for optical fibres and cables — Generic specification	Technically Equivalent

The technical committee has reviewed the provision of the following International Standard referred in this adopted standard and has decided that it is acceptable for use in conjunction with this standard:

International Standard	*Title*
IEC 60050-731 : 1991	International Electrotechnical Vocabulary — Chapter 731: Optical fibre communication

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

IS 15077 (Part 2) : 2012
IEC 62007-2 : 2009

Indian Standard

SEMICONDUCTOR OPTOELECTRONIC DEVICES FOR FIBRE OPTIC SYSTEM APPLICATIONS

PART 2 MEASURING METHODS

(First Revision)

1 Scope

This part of IEC 62007 describes the measuring methods applicable to the semiconductor optoelectronic devices to be used in the field of fibre optic digital communication systems and subsystems.

All optical fibres and cables that are defined in IEC 60793 series, IEC 60794 series are applicable. All optical connectors that are defined in IEC 60874 series are applicable, if a pigtail is to be terminated with an optical connector.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-731:1991, *International Electrotechnical Vocabulary – Chapter 731: Optical fibre communication*

IEC 60793 (all parts), *Optical fibres*

IEC 60794 (all parts), *Optical fibre cables*

IEC 60874 (all parts), *Connectors for optical fibres and cables*

3 Terms, definitions and abbreviations

For the purposes of this document, the following terms, definitions and abbreviations apply.

3.1 Terms and definitions

3.1.1
PIN photodiode
photodiode with a large intrinsic region sandwiched between p- and n-doped semiconducting regions used for the detection of optical radiation

[IEV 731-06-29]

3.1.2
avalanche photodiode
photodiode operating with a bias voltage such that the primary photocurrent undergoes amplification by cumulative multiplication of charge carriers

[IEV 731-06-30]

3.1.3
pigtail
short optical fibre or optical fibre cable that is attached to a device being measured

3.2 Abbreviations

LED	light emitting diodes
LD	laser diode
PD	photodiode
TIA	transimpedance amplifier
APD	avalanche photodiode

4 Measuring methods for photoemitters

4.1 Outline of the measuring methods

The LEDs and LDs have various opto-electronic properties. Some of them are important specifications for using them in the optical communication systems. The measuring methods for their opto-electronic properties are described in the following subclauses. Each subclause consists of following items.

a) Purpose
b) “Equipment setup” or “Circuit diagram” for measurement
c) “Equipment descriptions and requirements” or “Circuit descriptions and requirements”
d) Precautions to be observed
e) Measurement procedures
f) Specified conditions

4.2 Radiant power or forward current of LEDs and LDs with or without optical fibre pigtails

a) Purpose

To measure the radiant power Φ_e or the forward current I_F of light-emitting diodes (LED) and laser diodes, with or without optical fibre pigtails, under specified conditions.

b) Measuring equipment

Figure 1 shows an equipment setup for measuring radiant power and forward current of LEDs and LDs.

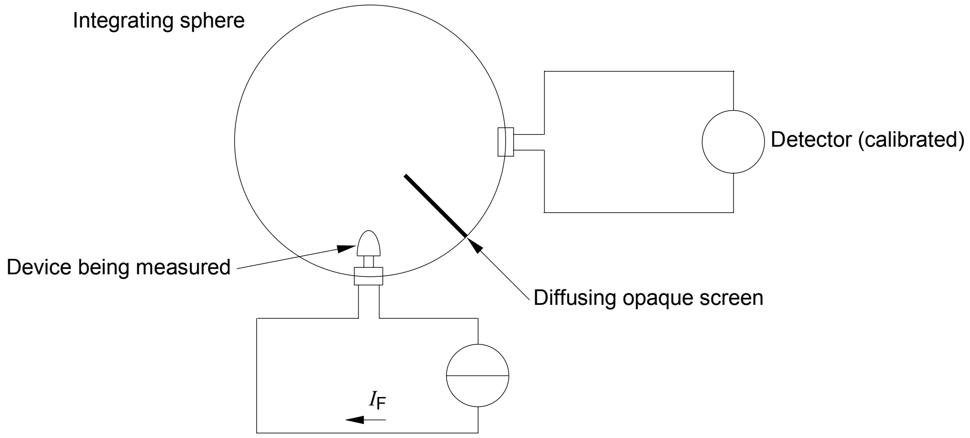


Figure 1 – Equipment setup for measuring radiant power and forward current of LEDs and LDs

c) Equipment description and requirements

The radiation emitted by the device is submitted to multiple reflections from the walls of the integrating sphere; this leads to a uniform irradiance of the surface proportional to the emitted flux. A detector located in the walls of the sphere measures this irradiance. An opaque screen shields the detector from the direct radiation of the device being measured.

d) *Precautions to be observed*

The device being measured, the screen and the apertures shall be small compared to the sphere surface.

The inner surface of the sphere and screen shall have a diffusing coating having a high uniform reflection coefficient (0,8 minimum).

The sphere and detector assembly shall be calibrated.

Change in peak-emission wavelength and flux due to power dissipation shall be taken into account.

When the device being measured is pulsed, the detector shall average the measured radiation.

e) *Measurement procedures*

The emitting device is set at the entrance of the integrating sphere, so that no direct radiation will reach the detector.

For measurement of radiant power, the specified forward current I_F is applied to the device and the radiant power is measured on the photodetector.

For measurement of forward current, a current is applied to the device until the specified radiant power (Φ_e) is achieved. The value of current is recorded.

f) *Specified conditions*

- Ambient or case temperature.
- Radiant power (when measuring forward current).
- Forward current (when measuring radiant power).

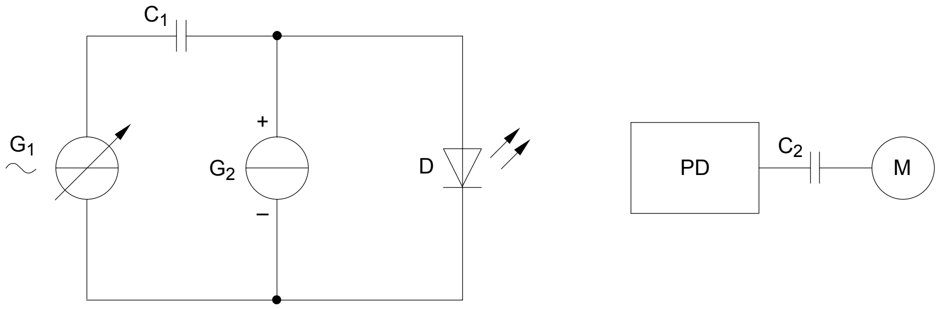
4.3 Small signal cut-off frequency (f_c) of LEDs and LDs with or without optical fibre pigtails

a) *Purpose*

To measure the small-signal cut-off frequency (f_c) of light-emitting diodes (LED) and laser diodes (LD) with or without optical fibre pigtails, under specified conditions.

b) *Circuit diagram*

Figure 2 shows a circuit diagram for measuring small-signal cut-off frequency LEDs and LDs.



Key

D	device being measured
G_1	adjustable frequency a.c. generator
G_2	d.c. generator
PD	photodetector
M	measuring instrument for a.c. radiant power
C_1, C_2	coupling capacitors

Figure 2 – Circuit diagram for measuring small-signal cut-off frequency LEDs and LDs

c) *Precautions to be observed*

The radiant power reflected back into the laser-diode shall be minimized so as to avoid distortions, which could affect the accuracy of the measurements. The photodetector must have a frequency response greater than f_c.

d) *Measurement procedure*

For LEDs, the specified direct forward current or the direct forward current required to obtain the specified radiant power is applied to the device being measured.

For laser diodes, the forward current is adjusted to a value equal to the continuous forward current above the threshold or specified radiant power.

The forward current is modulated using generator G_1 at a low frequency (less than f_c /100) and the a.c. radiant power is measured on M (see Figure 2).

The modulation frequency is increased, keeping the modulation level constant until the output radiant power measured on M has halved.

This frequency is the small-signal cut-off frequency (f_c).

e) *Specified conditions*

For the light-emitting diodes (LED):

- ambient or case temperature;
- d.c. forward current or radiant power.

For the laser diodes (LD):

- ambient, case or submount temperature;
- difference between (actual) d.c. forward current and threshold current or radiant power.

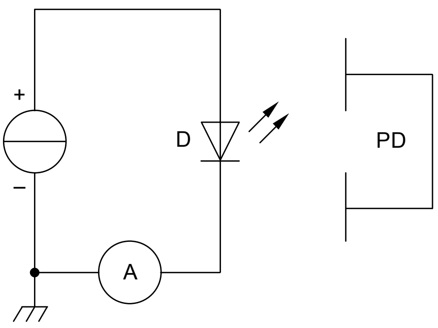
4.4 Threshold current of LDs with or without optical fibre pigtails

a) *Purpose*

To measure the threshold current of a laser diode, with or without optical fibre pigtails.

b) *Circuit diagram*

Figure 3 shows a circuit diagram for measuring threshold current of a laser diode.



Key

D	device being measured
PD	photodetector measuring incident radiant power
A	ammeter
G	generator (pulsed or d.c.)

Figure 3 – Circuit diagram for measuring threshold current of a LD

c) *Circuit description and requirements*

For pulse measurement, the current generator, G, shall provide current pulses of the required amplitude, duration and repetition rate.

d) *Precautions to be observed*

Radiant power reflected back into the laser diode shall be minimized. The limiting values of the laser diode (I_F and Φ_e) shall not be overstepped.

e) *Measurement procedure*

A forward current is applied to the diode and the relation between the incident radiant power from the diode and the forward current is recorded.

The forward current at which the second derivative of the recorded curve showing incident radiant power versus the forward current has its first maximum is determined (see Figure 4). The forward current at this point is the threshold current I_{TH}.

f) *Specified conditions*

- Ambient, case or submount temperature.
- For pulse measurement, repetition frequency and pulse duration of the forward current.

Figure 4 shows a graph to determine threshold current of lasers.

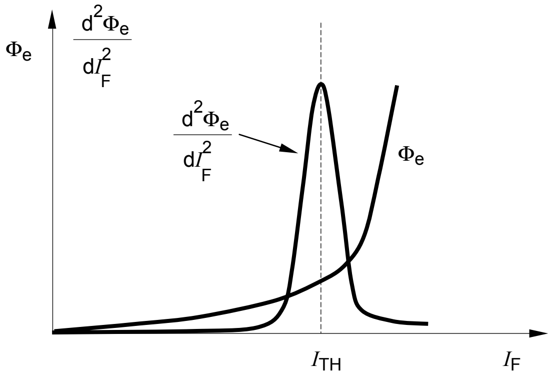


Figure 4 – Graph to determine threshold current of lasers

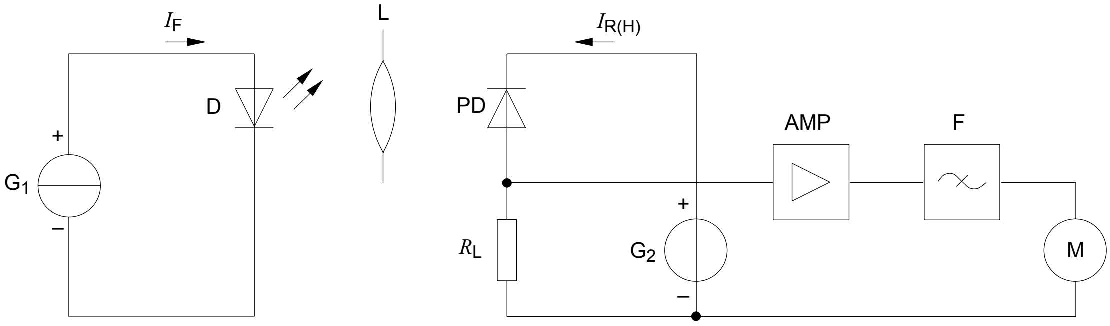
4.5 Relative intensity noise of LEDs and LDs with or without optical fibre pigtails

a) *Purpose*

To measure the relative intensity noise (RIN) of light emitting diodes (LED) and laser diodes (LD), with or without optical fibre pigtails, under specified conditions.

b) *Circuit diagram*

Figure 5 shows a circuit diagram for measuring RIN of LEDs and LDs.



Key

G_1	d.c. current generator
D	device being measured
L	lens system
I_F	forward current
PD	photodetector
R_L	load resistance
$I_{R(H)}$	reverse current of the photodetector under optical radiation
G_2	d.c. voltage bias generator
AMP	a.c. amplifier with gain G
F	filter with centre frequency f_0 and equivalent noise bandwidth Δf_N
M	measuring instrument (for example level meter, etc.)

Figure 5 – Circuit diagram for measuring RIN of LEDs and LDs

c) *Precautions to be observed*

Radiant power reflected back into the laser diode shall be minimized to avoid distortions affecting accuracy of the measurements.

d) *Measurement procedure*

A d.c. current corresponding to the specified radiant power Φ_e is applied to the device. The noise power N_t is measured by the measuring instrument M and is replaced by reverse current $I_{R(H)}$ of the photodetector, under optical radiation, which is measured simultaneously.

The photo-emitting device being measured is replaced by a radiation source with broad spectral radiation bandwidth in the same wavelength range.

The irradiant power is adjusted to obtain the same reverse current $I_{R(H)}$ of the photodetector under optical radiation as previously measured. The noise power N_d , which corresponds to the photodetector shot-noise plus amplifier noise, is measured by the measuring instrument.

RIN is calculated using the formula:

$$\mathrm{RIN} = \frac{N_\mathrm{t} - N_\mathrm{d}}{R_\mathrm{L} \times \mathrm{G} \times \Delta f_\mathrm{N} \times I_\mathrm{R(H)}}$$

It is expressed in Hz–1.

e) *Specified conditions*

- Ambient, case or submount temperature.
- Radiant power.
- Centre frequency and equivalent noise bandwidth.

4.6 S_{11} parameter of LEDs, LDs and LD modules with or without optical fibre pigtails

a) *Purpose*

To measure the real and imaginary parts (or modulus and phase) of the input characteristic of a device at a specified radiant power level and at a specified frequency.

The S_{11} parameter is the ratio of the high-frequency reflected voltage V_rl to the high-frequency incident voltage V_il at the device electrical input port.

$$S_{11} = \frac{V_\mathrm{rl}}{V_\mathrm{il}}$$

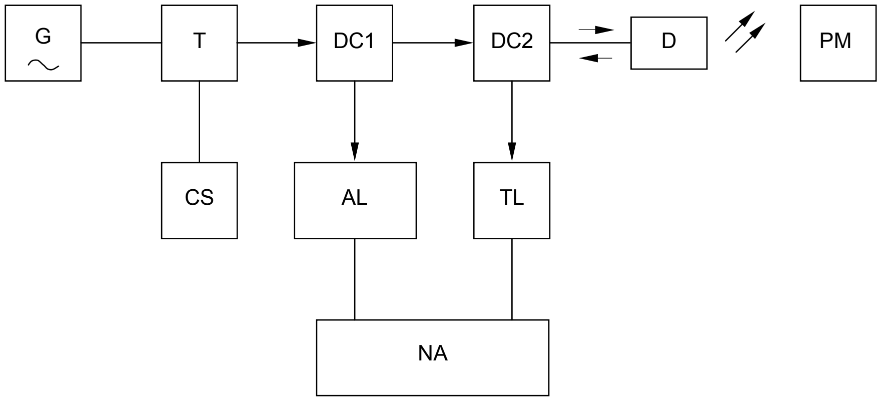
The equivalent working equation is the following:

$$S_{11} = \frac{Z_1 - Z_0}{Z_1 + Z_0}$$

where Z_1 is the input impedance of the device being measured and Z_0 the characteristic impedance of the measuring equipment.

b) *Circuit diagram*

Figure 6 shows the circuit diagram for measuring the S_{11} parameter LEDs, LDs and LD modules.



Key

G	r.f. generator
T	biasing circuit
CS	d.c. current source
DC1	directional coupler forward
DC2	directional coupler reverse
AL	adjustable transmission line
NA	network analyzer
D	device being measured
PM	radiant power meter
TL	test transmission line

Figure 6 – Circuit diagram for measuring the S_{11} parameter LEDs, LDs and LD modules

c) *Precautions to be observed*

The characteristic impedance of the transmission lines, generator, attenuators, device measuring socket, T-biasing circuit and loads is matched to a common impedance (usually 50 Ω) over the specified frequency range.

The RF power shall remain low enough to allow for linear operation of the device being measured D.

Ensure that the optical ports of the device D and the meter PM are aligned.

d) *Measurement procedure*

– *Calibration:*

The adjustable line shall balance the test line.

A short circuit is connected to the input line at the location of the device being measured D.

The a.c. signal frequency is scanned around the specified frequency f, and the adjustable line length is altered in order to obtain one single point S_{11} on the Smith chart (modulus equals to 1 and phase equals to 180 °).

– *Measurement:*

The "calibration" short-circuit is replaced by the device being measured D, the bias conditions are applied as specified (Φ_e, T_{case}, or T_{amb}, T_{sub}), the value of S_{11} corresponding to the reflection coefficient of the device D is read.

e) *Specified conditions*

– Ambient, case or submount temperature.

– Supply and drive conditions: Φ_e or I_F or ΔI_F, f, m (modulation depth).

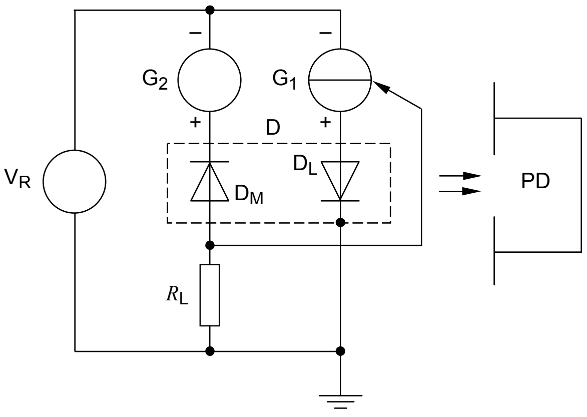
4.7 Tracking error for LD modules with optical fibre pigtails, with or without cooler

a) *Purpose*

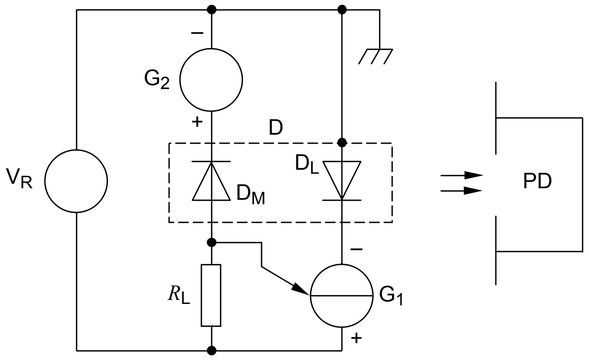
To measure the maximum variations of the tracking ratio between the fibre output radiant power and the monitor diode photocurrent of a laser module over a specified temperature range.

b) *Circuit diagrams*

Figure 7 shows a cathode and an anode connected to the package of a laser diode.



a) Laser diode: cathode connected to the package



b) Laser diode: anode connected to the package

Key

D	device being measured
PD	photodetector calibrated (in watts)
G_1	d.c. current source, monitored through negative feedback by the photocurrent delivered by the monitor photodiode
G_2	d.c. voltage source
R_L	load resistance
V_R	d.c. voltmeter
D_L	laser diode
D_M	monitor photodiode

Figure 7– Cathode and anode connected to the package of a LD

c) *Precautions to be observed*

The optical radiant power reflected back to the laser diode shall be minimized.

The changes in case temperature should be slow enough to insure that thermal equilibrium takes place inside the module and, in the case of a module with cooler, that the specified T_{sub} is stabilized.

d) *Measurement procedure*

At each measuring point, the current source G_1 is adjusted until the monitor photocurrent is equal to the value obtained with the specified optical radiation at 25 °C.

The case temperature is scanned over the specified range and the plot of the output radiant power is recorded against either time (Figure 8) or case temperature (Figure 9).

The tracking error is given by:

$$E_{\text{R1}} = \frac{\Phi_{\text{e25 °C}} - \Phi_{\text{emin}}}{\Phi_{\text{e25 °C}}} \times 100\ (\%) \qquad E_{\text{R2}} = \frac{\Phi_{\text{emax}} - \Phi_{\text{e25 °C}}}{\Phi_{\text{e25 °C}}} \times 100\ (\%)$$

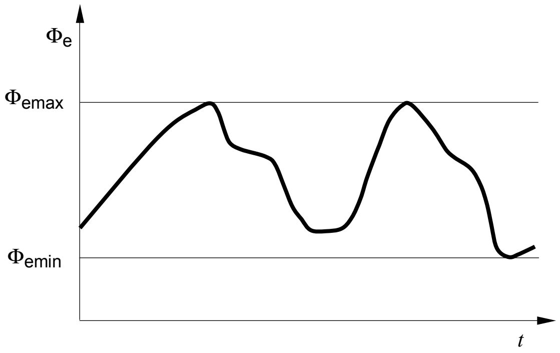


Figure 8 – Output radiant power versus time

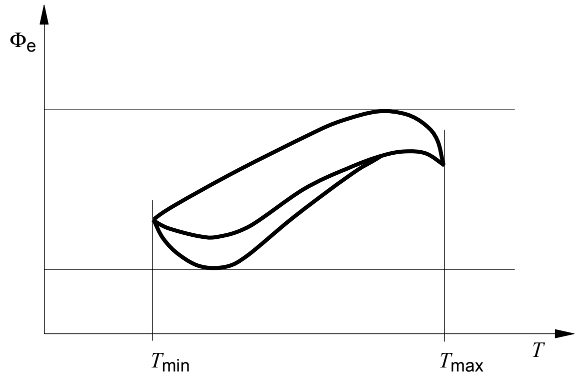


Figure 9 – Output radiant power versus case temperature

e) *Specified conditions*

- Φ_e or ΔI_F at 25 °C.
- Case or ambient temperature range $T_{\text{case/amb min}}$; $T_{\text{case/amb max}}$.
- Submount temperature (T_{sub}), where appropriate.
- Bias voltage (V_R) of the monitor photodiode (D_M).

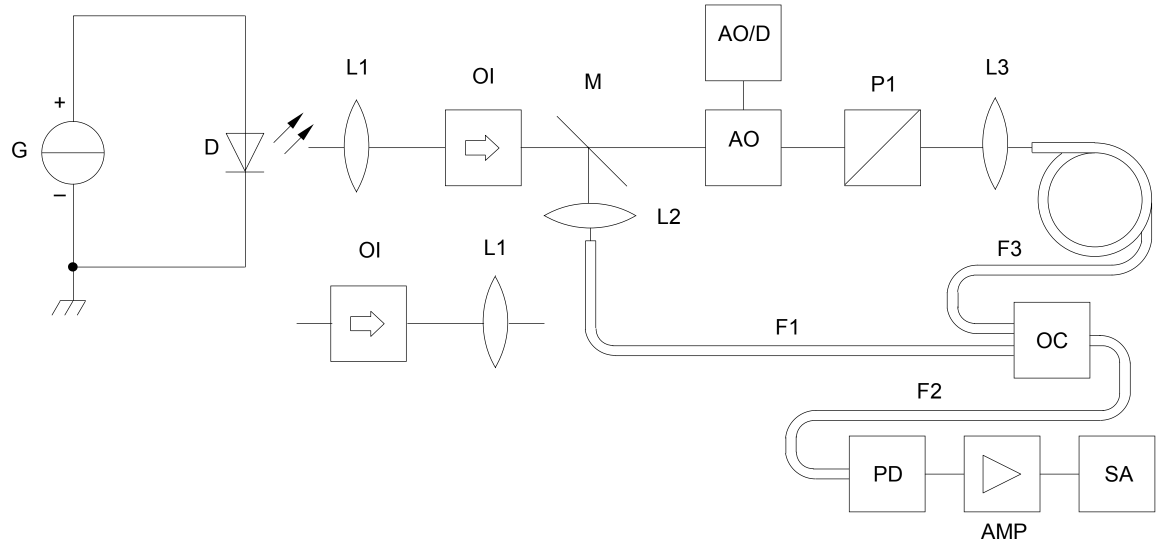
4.8 Spectral linewidth of LDs with or without optical fibre pigtails

a) *Purpose*

To measure the spectral linewidth of a laser diode (LD) with or without optical fibre pigtails.

b) *Circuit diagram*

Figure 10 shows a circuit diagram for measuring linewidth of LDs.



Key

G	d.c. current source
D	device being measured
L1, L2, L3	lenses
OI	optical isolator
AO	acousto-optic modulator
AO/D	driver for acousto-optic modulator
M	mirror
P1	polarization adjustment device
F1, F2, F3	single mode fibre
OC	optical coupler
PD	detector
AMP	amplifier
SA	spectrum analyzer

Figure 10 – Circuit diagram for measuring linewidth of LDs

c) *Precautions to be observed*

Radiation power reflected back into the laser diode shall be minimized.

Length of F3 should be sufficiently long to obtain a greater resolution than the spectral linewidth of the device being measured D.

Modulation frequency should be higher than the spectral linewidth of the device D.

The specified d.c. current should be sufficiently stabilized so as not to broaden the measured linewidth of the device D.

NOTE The fibre length of F3 should be determined by the frequency resolution:

$$\frac{0{,}75\ \mathrm{c}}{\pi\ L\ n}$$

where

c is the velocity of light;

L is the length of F3;

n is the refractive index of fibre F3.

d) Measurement procedure

The specifed d.c. current above threshold (ΔI_F) or the forward current corresponding to the specified radiant power (Φ_e) is applied to the device D being measured.

The optical port of the device D is aligned to get maximum radiant power into F1 and F3.

A peak corresponding to the modulation frequency of the modulator AO on the spectrum analyzer is observed and P1 is rotated to get the maximum radiant power. Full width at half maximum of the observed peak is measured. The measured value is twice the spectral linewidth of the device D.

e) Specified conditions

- Ambient, case or submount temperature.
- Forward current above threshold ΔI_F or radiant power Φ_e.

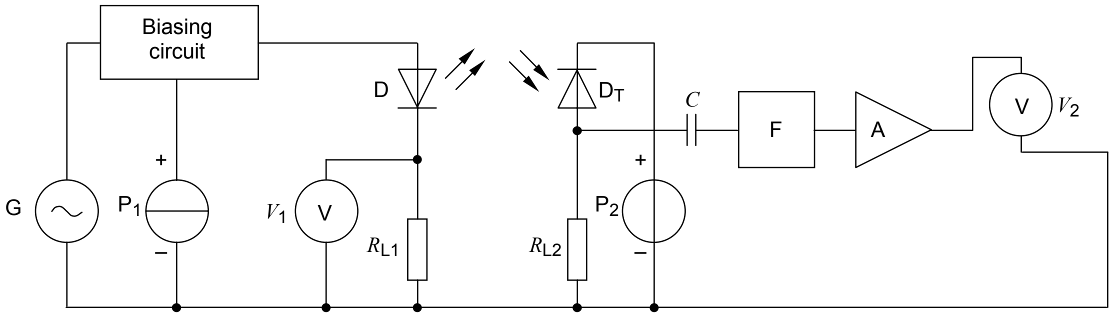
4.9 Modulation current at 1 dB efficacy compression ($I_{\mathrm{F\ (1\ dB)}}$) of LEDs

a) Purpose

To measure the modulation current at 1 dB efficacy compression under specified modulation frequency and radiant power output condition.

b) Circuit diagram

Figure 11 shows the circuit diagram for measuring 1-dB efficacy compression of LDs.



Key

D	device being measured
G	sine wave signal source
C	coupling capacitor
P_1	power supply to provide the specified radiant power Φ_e to D
V, V_1, V_2	a.c. voltmeter or broadband voltage measuring equipment
R_{L1}	load resistor for matching the specified electrical impedance of D
D_T	optical signal detector
R_{L2}	load resistor for matching the specified electrical impedance of D_T
P_2	power supply to provide the operating voltage to D_T
F	filter with bandpass centre frequency matched to the frequency f of the sine wave signal source
A	amplifier

Figure 11 – Circuit diagram for measuring 1 dB efficacy compression of LDs

c) *Precautions to be observed*

The optical port of the device being measured shall, as far as possible, be coupled to that of the optical signal detector.

d) *Measurement procedure*

Couple the optical output of D from the optical port to the detector D_T. Apply the supply current generated by P_1 to the appropriate connections of D so as to achieve the specified output radiant power Φ_e from the optical port. Apply modulation current from signal generator G at the specified modulation frequency. Record the detected signal voltage V_2 and the modulation voltage V_1 as the modulation current is increased. The modulation current I_1 ($I_1 = V_1/R_{L1}$) is determined from V_1 using the value of R_{L1}. Identify the region for which there is a linear relationship between log V_2 and log I_1. Record the value of I_1 at which log V_2 is 1 dB below the value resulting from the projected linear region, as shown in Figure 17. This value of I_1 is the modulation current at 1 dB efficacy compression $I_{F(1\ dB)}$.

NOTE The functions of the filters and a.c. voltmeters are typically incorporated in r.f. spectrum analyzer instruments. Such instruments can be used in place of the individual circuit elements shown in the circuit description. With this substitution, the measured quantities are a.c. signal powers in place of signal amplitudes.

Figure 12 shows the plot of log V_2 versus log I_1.

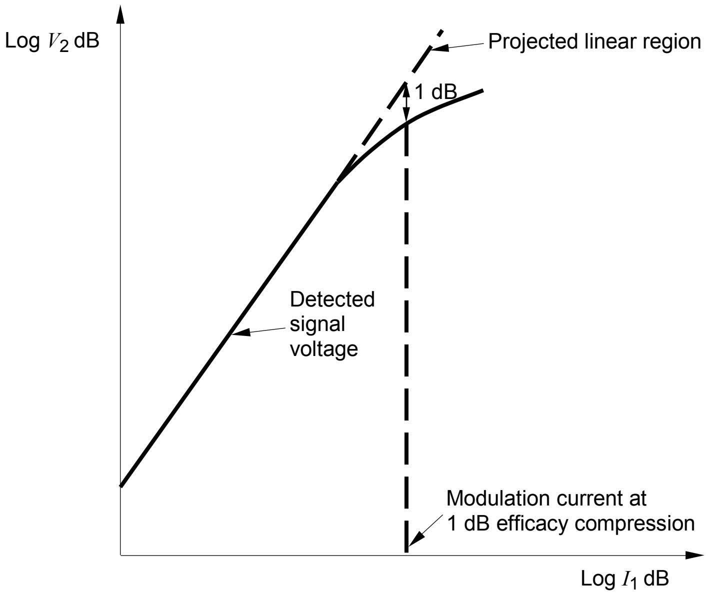


Figure 12 – Plot of log V_2 versus log I_1

e) *Specified conditions*

- Ambient or case temperature (T_{amb} or T_{case})
- Load resistances (R_{L1} and R_{L2})
- Peak-emission wavelength and spectral radiation bandwidth of the light source (λ_p, $\Delta\lambda$)
- Radiant power (Φ_e)
- Modulation frequency (f)

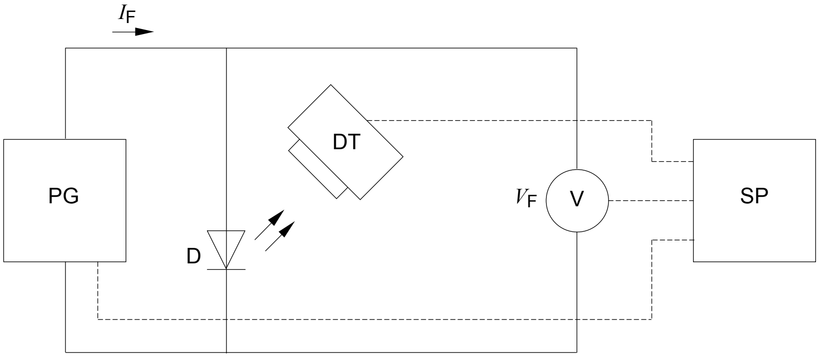
4.10 Differential efficiency (η_d) of a LD with or without pigtail and an LD module

a) *Purpose*

To measure the differential efficiency η_d of a laser diode (LD) with or without pigtail and an LD module.

b) *Circuit diagram and current waveform*

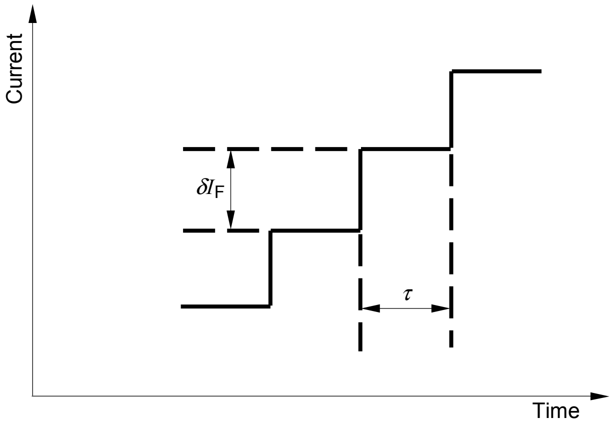
Figure 13 shows the circuit diagram for measuring differential efficiency of a LD and Figure 14 shows the current waveform for differential efficiency measurement.



Key

D	device being measured	I_F	forward current
PG	current step generator	V	voltmeter
D_T	photodetector	V_F	device forward voltage as measured on the voltmeter
SP	signal processing equipment		

Figure 13 – Circuit diagram for measuring differential efficiency of a LD



Key

δI_F	step-amplitude
τ	step duration

Figure 14 – Current waveform for differential efficiency measurement

c) Precautions to be observed

Radiant power reflected back into the laser diode shall be minimized. The limiting values of the laser diode, I_F or Φ_e, shall not be exceeded.

d) Measurement procedure

The current waveform applied to the device shall be as shown in Figure 16, where δI_F is the step-amplitude and $\leq (1/20)\Delta I_F$ and τ, the step duration, shall be of sufficient length to allow the device to achieve thermal equilibrium.

NOTE The step duration τ should not be too small, otherwise thermal effects would not be taken into account. A recommended minimum value is 100 µs, close to the most common chip-to-heatsink thermal time constant.

Record I_F and Φ_e at each step level.

Derive η_d from the ratio:

$$\eta_d = \delta\Phi_e / \delta I_F, \qquad \text{at } \Delta I_F \text{ or } \Phi_e \text{ specified.}$$

e) Specified conditions

- Ambient or case temperature, or sub-mount temperature (T_{amb}, T_{case} or T_{sub})
- Either forward current above threshold (ΔI_F) or radiant power (Φ_e)

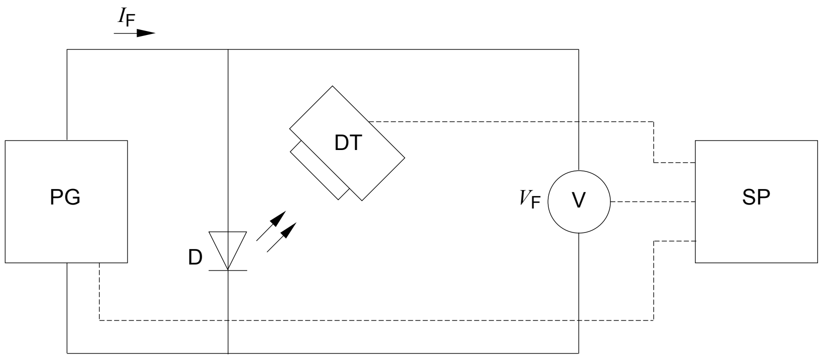
4.11 Differential (forward) resistance r_d of an LD with or without pigtail

a) Purpose

To measure the differential (forward) resistance r_d of a laser diode (LD) with/without pigtail.

b) Circuit diagram and current waveform

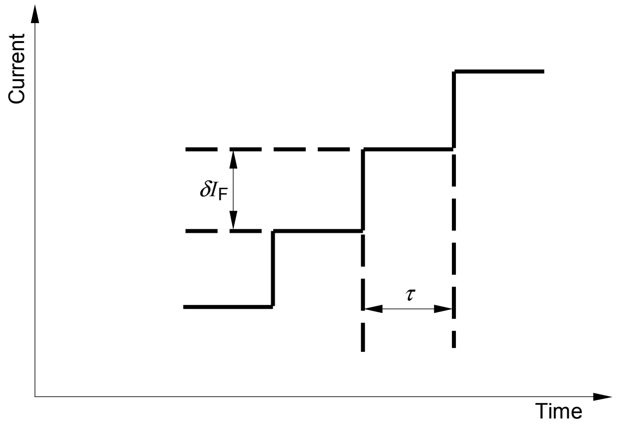
Figure 15 shows the circuit diagram for measuring differential resistance and Figure 16 shows the current waveform for differential resistance.



Key

D	device being measured	SP	signal processing equipment
PG	current step generator	I_F	forward current
V	voltmeter	V_F	device forward voltage as measured on the voltmeter
D_T	photodetector		

Figure 15 – Circuit diagram for measuring differential resistance



Key

δI_F	step-amplitude
τ	step duration

Figure 16 – Current waveform for differential resistance

c) *Precautions to be observed*

The limiting values of the laser diode, I_F or Φ_e, shall not be exceeded.

d) *Measurement procedure*

The current waveform applied to the device shall be as shown in Figure 16, where δI_F is the step-amplitude and $\leq(1/20)\Delta I_F$.

Record I_F, V_F and Φ_e at each step level.

Derive r_d from the ratio:

$$r_d = \delta V_F / \delta I_F, \qquad \text{at } \Delta I_F \text{ or } \Phi_e \text{ specified.}$$

e) *Specified conditions*

- Ambient or case temperature, or submount temperature (T_{amb}, T_{case} or T_{sub})
- Either forward current above threshold (ΔI_F) or radiant power (Φ_e)

5 Measuring methods for receivers

5.1 Outline of the measuring methods

The photodiodes have various opto-electronic properties. Some of them are important specifications for using them in the optical communication systems. The measuring methods for their opto-electronic properties are described in the following subclauses. Each subclause consists of following items.

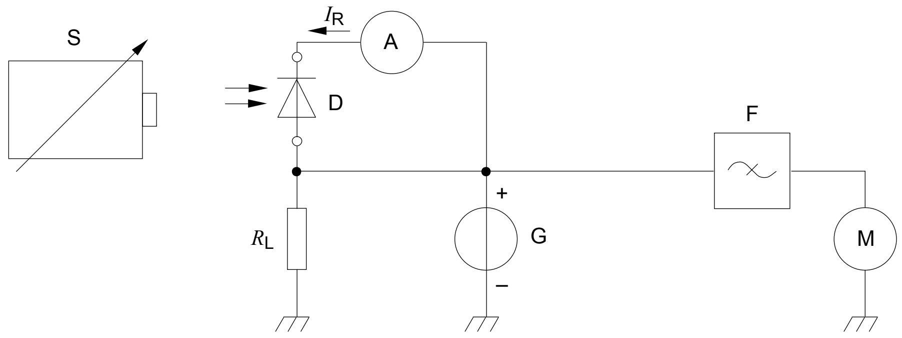
5.2 Noise of a PIN photodiode

a) *Purpose*

To measure the noise current, the noise power, the detectivity or the noise equivalent power (NEP) of a PIN photodiode under specified conditions.

b) *Circuit diagram*

Figure 17 shows the circuit diagram for measuring noise of a PIN photoreceiver.



Key

S	radiation or light source
D	device being measured
I_R	reverse current under optical radiation
R_L	load resistance (50 Ω preferably)
A	ammeter
G	reverse-voltage supply
F	filter with specified maximum transmission frequency (centre frequency) f_0 and specified equivalent noise bandwidth Δf_N
M	true r.m.s. reading instrument, calibrated in noise current, noise power, detectivity or equivalent noise power

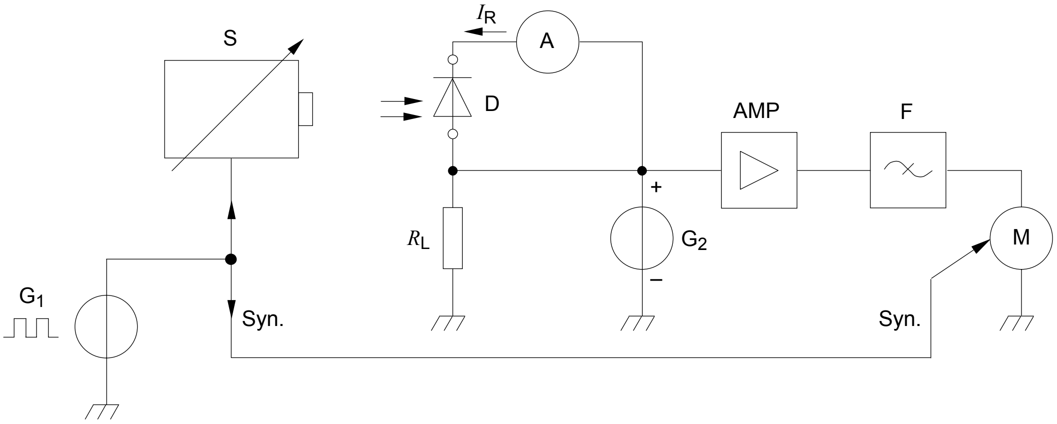
Figure 17 – Circuit diagram for measuring noise of a PIN photoreceiver

c) *Precautions to be observed*

The bandwidth should be defined by the filter F, taking into account the other parameters, such as the capacitance of D and the input capacitance of the measuring equipment.

The noise of the measuring equipment, including the radiation or light source, should be small compared with the noise to be measured or should be taken into account in the measurement result.

When the noise level is too low to be measured directly, amplification and synchronous detection techniques may be used as described below in Figure 18.



Key

G_1	modulation generator, square wave (δ = 0,5), frequency f_1
S	radiation or light source
I_R	reverse current under optical radiation
D	device being measured
R_L	load resistor
A	ammeter
G_2	reverse voltage supply
AMP	a.c. amplifier
F	filtre (centre frequency f_0, equivalent noise bandwidth Δf_N)
M	true r.m.s. reading instrument
Syn.	synchronisation signal

NOTE 1 f_1 is low compared with f_0 (centre frequency of the filter F).

NOTE 2 The filter F rejects the frequency f_1.

Figure 18 – Circuit diagram for measuring noise with synchronous detection

d) *Measurement procedure*

The measuring equipment being calibrated, the specified reverse voltage V is applied to the device being measured D. The radiant or luminous flux of the source is increased from 0 until the specified value of I_R is reached. The noise of the device D is measured on the reading instrument M.

e) *Specified conditions*

- Ambient temperature.
- Characteristics of the radiation of light source: either peak-emission wavelength, λ_p, and spectral bandwidth $\Delta\lambda$, or spectral distribution (for example illuminant A).
- Reverse voltage source (V).
- Reverse current under optical radiation (I_R).
- Load resistance (R_L) if other than 50 Ω.
- Filter maximum transmission frequency (centre frequency) (f_0) and equivalent noise bandwidth (Δf_N).

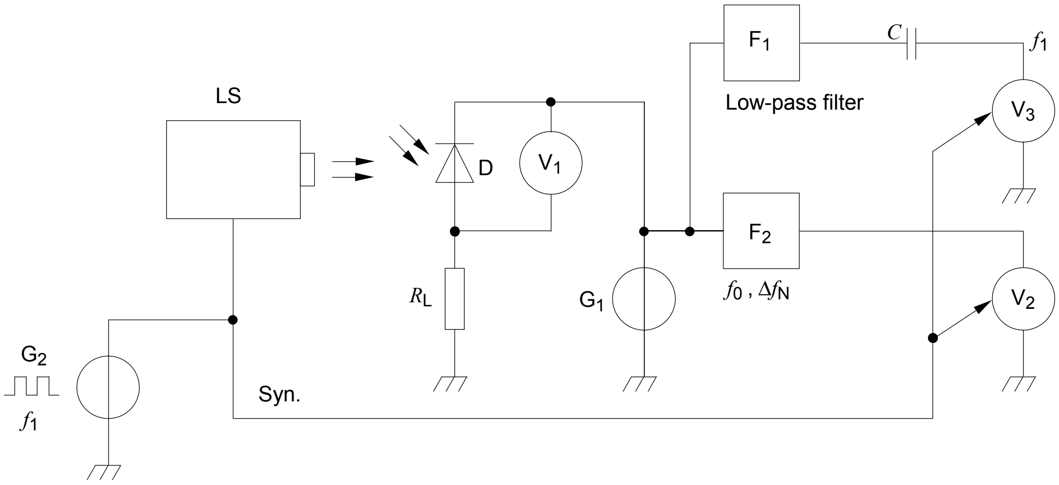
5.3 Excess noise factor of an APD with or without optical fibre pigtails

a) *Purpose*

To measure the excess noise factor F_e of an avalanche photodiode (APD) with or without optical fibre pigtails.

b) *Circuit diagram*

Figure 19 shows the circuit diagram for measuring excess noise of an APD.



Key

LS	radiation or light source
D	device being measured
R_L	load resistance
G_1	d.c. voltage source
G_2	optical modulation generator with frequency f_1
V_1	d.c. voltmeter
V_2	true r.m.s. voltage meter with synchronous amplifier at frequency f_1
V_3	a.c. voltage meter with synchronous amplifier at frequency f_1
F_1	low-pass filter
F_2	band-pass filter with specified central frequency f_0 and bandwidth Δf_N
C	d.c. blocking capacitor
Syn.	synchronization signal

NOTE 1 Modulation frequency f_1 should be low compared to f_0 and to prevent measuring error due to frequency response of the device D being measured.

NOTE 2 Filter F_2 should reject modulation frequency f_1.

NOTE 3 Filter F_1 should pass modulation frequency f_1 but reject frequencies larger than $f_0 - \Delta f_N/2$.

NOTE 4 Capacitor value C should be large enough to pass frequency f_1.

NOTE 5 Only the optical port of the device D being measured should be irradiated and that irradiation should completely fill the port.

Figure 19 – Circuit diagram for measuring excess noise of an APD

c) *Procedure*

1) Apply a low-bias voltage V_{R1} measured by V_1.

   V_{R1} should be sufficiently low so that negligible carrier multiplication takes place (i.e. multiplication factor $M \approx 1$) but sufficiently large that the device is fully depleted and has achieved its rated speed and responsivity. Adjust the input optical power to achieve the specified photocurrent $I_{po(3)}$ as measured by voltage V_{30} on V_3 from the signal modulated at frequency f_1 using the relationship:

$$I_{po} = \frac{1}{k} \times \frac{V_{30}}{R_L}$$

where k is equal to the duty factor of modulation generator G_2 (e.g. for a 50 % duty factor square wave, $k = 1/2$).

2) Increase bias voltage V_R until the voltage V_{31} read on V_3 reaches the value $M \times V_{30}$:

$$M = \frac{V_{31}}{V_{30}}$$

3) Read the voltage V_{21} on V_2 and calculate the excess noise factor F_e from the relationship:

$$F_e = \frac{{V_{21}}^2}{2\, q \times I_{po} \times M^2 \times {R_L}^2 \times \Delta f_N}$$

where q is the electronic charge.

d) Precautions to be observed

This method is not accurate for a device in which unity gain ($M \approx 1$) cannot be achieved when the device is fully depleted and has achieved its rated speed and responsivity.

e) Specified conditions

- Ambient or case temperature.
- Multiplication factor (M).
- Photocurrent (I_{po}).
- f_o, Δf_N of the filter F_2.
- Peak emission wavelength and spectral radiation bandwidth (λ_p, $\Delta\lambda$).
- V_{R1}.

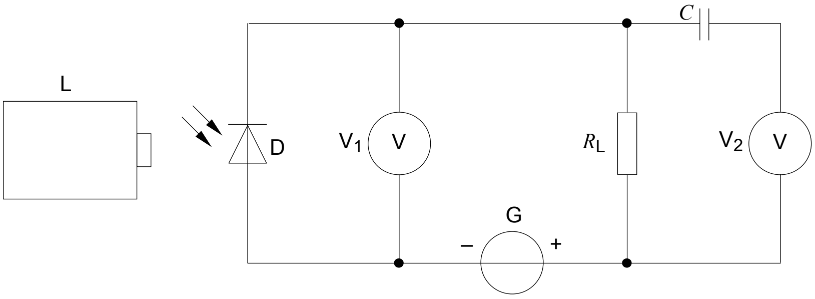
5.4 Small-signal cut-off frequency of a photodiode with or without optical fibre pigtails

a) Purpose

To measure the small-signal cut-off frequency of a photodiode, with or without optical fibre pigtails, under specified conditions.

b) Circuit diagram

Figure 20 shows the circuit diagram for measuring small-signal cut-off wavelength of a photodiode.



Key

D	device being measured
L	narrowband light source emitting light which is amplitude modulated with a small-signal sinusoidal wave of adjustable frequency
G	d.c. voltage source
V_1	d.c. voltmeter
V_2	broadband voltage measurement instrument
R_L	load resistance, low in value compared with the source resistance of the device being measured
C	coupling capacitor

Figure 20 – Circuit diagram for measuring small-signal cut-off wavelength of a photodiode

c) *Precaution to be observed*

Only the optical port of the device shall be completely irradiated.

d) *Measurement procedure*

The specified direct reverse voltage is applied to the device being measured. The radiation source is adjusted to obtain the average value Φ_e specified from the optical port. This source is modulated at a low frequency (less than f_c / 100) and the a.c. output signal is measured on V_2.

The modulation frequency of the radiation source is increased keeping the average value of Φ_e and the modulation level constant until the output signal measured on V_2 has decreased by $\sqrt{2}$. This frequency is the small-signal cut-off frequency f_c.

e) *Specified conditions*

- Ambient or case temperature.
- Reverse voltage (V_R).
- Load resistance (R_L).
- Peak-emission wavelength and spectral radiation bandwidth of the light source (λ_p, $\Delta\lambda$).
- Radiant power (Φ_e).

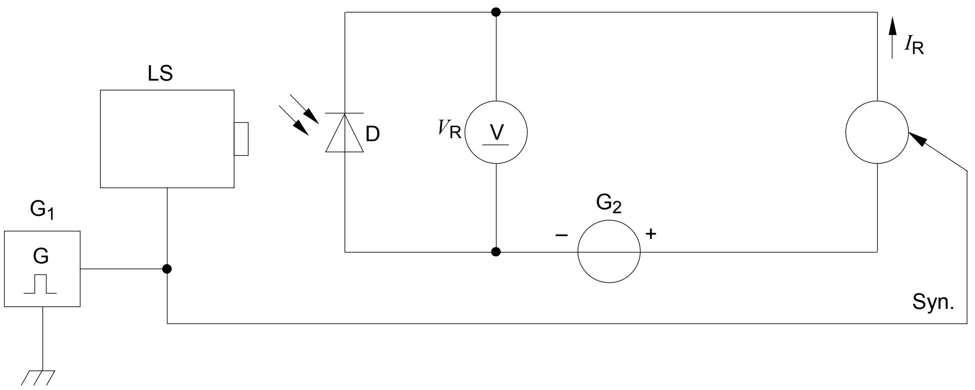
5.5 Multiplication factor of an APD with or without optical fibre pigtails

a) *Purpose*

To measure the multiplication factor M of an avalanche photodiode (APD) with or without optical fibre pigtails.

b) *Circuit diagram*

Figure 21 shows the circuit diagram for measuring multiplication factor of an APD.



Key

LS	radiation or light source
D	device being measured
G_1	modulation generator
G_2	d.c. voltage source
SA	synchronous ammeter
Syn.	synchronization signal
G	signal source
V	voltmeter
V_{R}	tension de polarisation

Figure 21 – Circuit diagram for measuring multiplication factor of an APD

c) *Precautions to be observed*

Only the optical port of the device being measured shall be considered.

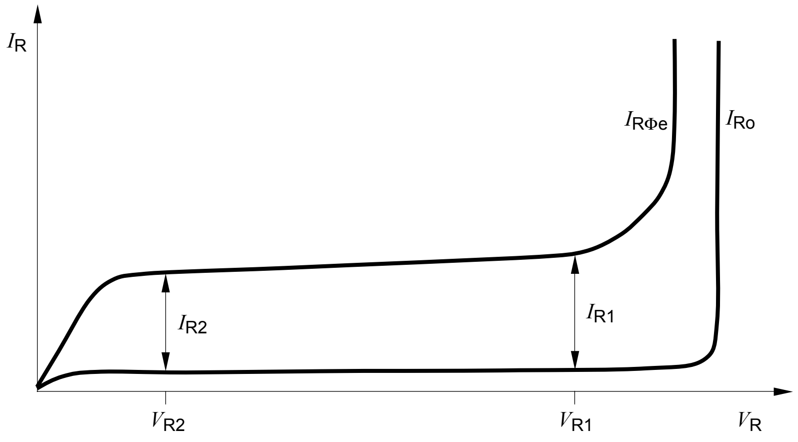
d) *Measurement procedure*

Apply the specified low bias voltage V_{R2} from the generator G_2 to the device being measured. Adjust the radiant power Φ_{e} to the specified value. Measure the current I_{R2} on the synchronous ammeter.

Change the d.c. bias voltage applied to the device being measured to the specified value V_{R1}. Measure the current I_{R1} on the synchronous ammeter. Figure 22 shows the graph of measures of I_{R1} and I_{R2}.

Calculate the multiplication factor M from the equation:

$$M = \frac{I_{\mathrm{R1}}}{I_{\mathrm{R2}}}$$



Key

I_{Ro}	dark current
$I_{R\phi e}$	current under optical radiation
V_R	tension de polarisation

Figure 22 – Graph showing measurement of I_{R1} and I_{R2}

e) Specified conditions

- Ambient or case temperature.
- Reverse voltages (V_{R1}, V_{R2}).
- Radiant power (Φ_e).
- Peak emission wavelength (λ_p).
- Spectral radiation bandwidth ($\Delta\lambda$).
- Optical port.
- Optical configuration.

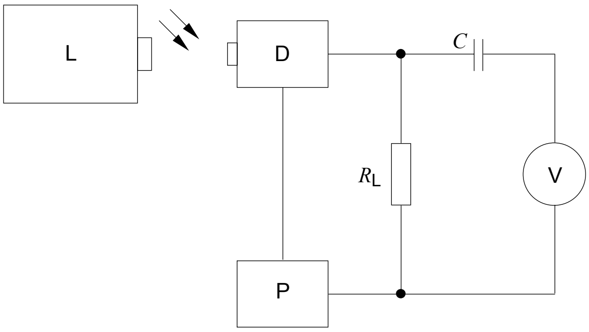
5.6 Responsivity of a PIN-TIA module

a) Purpose

To measure the responsivity of a PIN-TIA module under specified modulated radiation input condition.

b) Circuit diagram

Figures 23 shows the circuit diagram for measuring responsivity of a PIN-TIA module.



Key

D	device being measured
L	narrowband radiation source with adjustable radiant power Φ_e and which is amplitude modulated with a small-signal sinusoidal wave of adjustable frequency and r.m.s. value $\Delta\Phi_{e(r.m.s)}$
P	power supply to provide specified operating voltages and currents to D
R_L	load resistor for matching the specified output impedance of D
C	coupling capacitor
V	r.m.s. voltmeter or broadband voltage measuring instrument

Figure 23 – Circuit diagram for measuring responsivity of a PIN-TIA module

c) *Precautions to be observed*

The optical port of the device being measured shall be completely irradiated.

The value of $\Delta\Phi_{e(r.m.s)}$ shall be sufficiently smaller than the d.c. radiant power Φ_e, and stay constant over the specified band of modulation frequencies f_1 to f_2.

A signal shall be considered small if a two-to-one increase in its magnitude does not produce a change in the measured value of the parameter that is greater than the permitted error of the measurement.

d) *Measurement procedure*

Apply specified supply voltages generated by P to the appropriate connections of D. Adjust L to provide the specified d.c. value of input radiant power Φ_e and the specified modulation frequency. Measure the r.m.s. a.c. output voltage $V_{o(r.m.s)}$ on V. Determine the responsivity S using the following relationship:

$$S = \frac{V_{0(rms)}}{\Delta\Phi_{e(rms)}}$$

Note the maximum (S_{max}) and minimum (S_{min}) values of S measured in the frequency range f_1 to f_2, as well as the mid-band central value S_{mb} defined by:

$$F_{mb} = \sqrt{f_1 \times f_2}$$

or corresponding to a specified value.

NOTE The functions of the load resistor, coupling capacitor and a.c. voltmeter are typically incorporated in r.f. spectrum/network analyzers. Such instruments can be used in place of the individual circuit elements shown in the circuit description.

e) *Specified conditions*

- Ambient or case temperature (T_{amb} or T_{case}).
- Specified supply voltages generated by P.
- Load resistance (R_L).

- Peak-emission wavelength and spectral radiation bandwidth of the light source (λ_p, $\Delta\lambda$).
- d.c. radiant power (Φ_e).
- Modulation frequency (f).

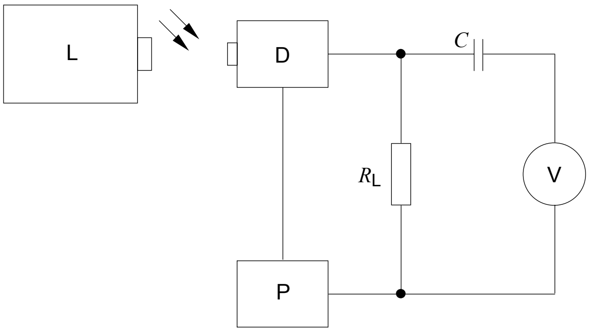
5.7 Frequency response flatness ($\Delta S/S$) of a PIN-TIA module

a) *Purpose*

To measure the frequency response flatness of a PIN-TIA module over a specified band of modulation frequencies.

b) *Circuit diagram*

Figure 24 shows the circuit diagram for measuring frequency response flatness of a PIN-TIA module.



Key

D	device being measured
L	narrowband radiation source with adjustable radiant power Φ_e and which is amplitude modulated with a small-signal sinusoidal wave or adjustable frequency and r.m.s. value $\Delta\Phi_{e(r.m.s)}$
P	power supply to provide specified operating voltages and currents to D
R_L	load resistor for matching the specified output impedance of D
C	coupling capacitor
V	a.c. voltmeter or broadband voltage measuring instrument

Figure 24 – Circuit diagram for measuring frequency response flatness of a PIN-TIA module

c) *Precautions to be observed*

The optical port of the device being measured shall be completely irradiated.

The value $\Delta\Phi_{e(r.m.s)}$ shall be sufficiently smaller than the d.c. radiant power Φ_e and substantially constant over the specified band of modulation frequencies f_1 to f_2.

A signal shall be considered small if a two-to-one increase in its magnitude does not produce a change in the measured value of the parameter that is greater than the permitted error of the measurement.

d) *Measurement procedure*

Apply specified supply voltages generated by P to the appropriate connections of D. Adjust L to provide the specified d.c. value of input radiant power Φ_e. Vary the modulation frequency over the specified band of frequencies f_1 to f_2. Measure the a.c. output voltage $V_{o(r.m.s)}$ on V as a function of frequency. Determine the responsivity S using the following relationship:

$$S = \frac{V_{0(rms)}}{\Phi_{e(rms)}}$$

Determine the maximum (S_{max}) and minimum (S_{min}) values of S over the specified band of modulation frequencies, and its value $S(f_{\mathrm{mb}})$ at the mid-band frequency f_{mb}. The frequency response flatness, expressed in decibels, is calculated as:

$$\Delta S / S = 10 \log \frac{S_{\mathrm{max}} - S_{\mathrm{min}}}{S_{\mathrm{mb}}}$$

where f_{mb} is the mid-band frequency defined by $f_{\mathrm{mb}} = \sqrt{f_1 \times f_2}$, unless otherwise specified, and $S(f_{\mathrm{mb}})$ is the responsivity value at the frequency f_{mb}.

NOTE The functions of the load resistor, coupling capacitor and a.c. voltmeter are typically incorporated in r.f. spectrum/network analyzer instruments. Such instruments can be used in place of the individual circuit elements shown in the circuit description.

e) *Specified conditions*

- Ambient or case temperature (T_{amb} or T_{case}).
- Specified bias voltages generated by P.
- Load resistance (R_{L}).
- Peak-emission wavelength and spectral radiation bandwidth of the light source (λ_{p}, $\Delta\lambda$).
- DC radiant power (Φ_{e}).
- Modulation frequency range of radiant power (f_1, f_2).
- Mid-band frequency (f_{mb}), if other than $\sqrt{f_1 \times f_2}$.

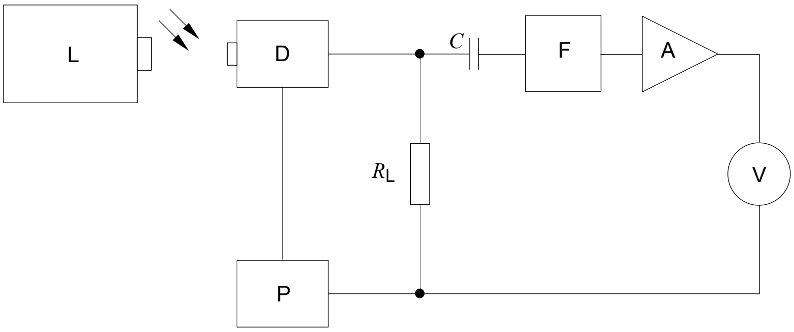
5.8 Output noise power (spectral) density $P_{\mathrm{no},\lambda}$ of a PIN-TIA module

a) *Purpose*

To measure the output noise power spectral density of a PIN-TIA module under matched-output conditions.

b) *Circuit diagram*

Figure 25 shows the circuit diagram for measuring output noise power (spectral) density of a PIN-TIA module under matched output conditions.



Key

D	device being measured
L	narrowband radiation source with adjustable radiant power Φ_e
P	power supply to provide specified operating voltages and currents to D
R_L	load resistor for matching the specified electrical impedance of D
F	high-Q bandpass filter
A	amplifier with voltage gain G_v
V	true r.m.s. noise voltage measuring instrument to measure the output noise voltage V_m at frequency f_m
C	coupling capacitor

Figure 25 – Circuit diagram for measuring output noise power (spectral) density of a PIN-TIA module under matched output conditions

c) *Precautions to be observed*

The optical port of the device being measured shall be completely irradiated with the specified input radiant power Φ_e.

The bandwidth of the amplifier shall be sufficiently large to ensure that the overall noise bandwidth is determined by filter F.

The measuring circuit shall be electrically grounded and shielded so as to prevent spurious signals from interfering with the measurement of low-level noise signals.

d) *Measurement procedure*

Apply specified supply voltages and currents provided by P to the appropriate connections of D.

Adjust L to provide at the optical port of D the specified input radiant power Φ_e.

Adjust the centre frequency of F to the specified frequency f_m for the measurement of the output noise power (spectral) density.

Read the value V_m of the output r.m.s. noise voltage at voltmeter V.

Calculate the output noise power (spectral) density as:

$$P_{no,\lambda} = \frac{(V_m / G_v)^2}{R_L \times B}$$

NOTE The functions of the load resistor, filter, amplifier and r.m.s. noise voltmeter are typically incorporated in r.f. spectrum analyzer instruments. Such instruments can be used in place of the individual circuit elements shown in the circuit diagram.

e) *Specified conditions*

- Ambient or case temperature (T_{amb} or T_{case}).
- Specified supply voltages and currents provided by P.
- Load resistance (R_L).

- Peak-emission wavelength and spectral radiation bandwidth of the light source (λ_p, $\Delta\lambda$).
- Input radiant power (Φ_e).
- Centre frequency (f_m) and effective bandwidth (B) of F.

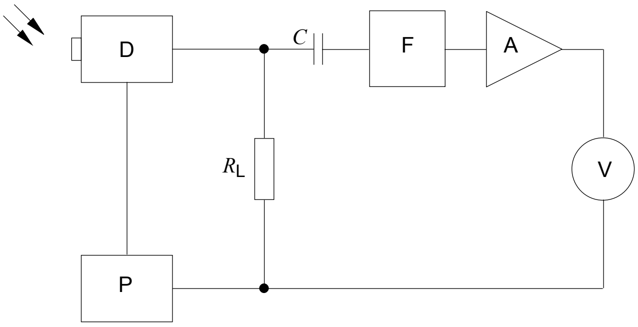
5.9 Low frequency output noise power (spectral) density ($P_{no,\lambda,LF}$) and corner frequency (f_{cor}) of a PIN-TIA module

a) Purpose

To measure the output noise power (spectral) density of a non-irradiated PIN-TIA module in the low frequency region, where it is dominated by the so-called 1/f noise, and corner frequency, under matched-output condition.

b) Circuit diagram

Figure 26 shows a circuit diagram for measuring output noise power (spectral) density of a non-irradiated PIN-TIA module in the low frequency region.



Key

D	device being measured (non-irradiated)
P	power supply to provide specified supply voltages and currents to D
R_L	load resistor for matching the specified output impedance of D
F	high-Q bandpass filter with adjustable centre frequency f_m and effective bandwidth B
A	amplifier with voltage gain G_v
V	true r.m.s. voltage measuring instrument to measure the output noise voltage V_m at frequency f_m
C	coupling capacitor

Figure 26 – Circuit diagram for measuring output noise power (spectral) density of a non-irradiated PIN-TIA module in the low frequency region

c) Precautions to be observed

The optical port of D shall not be irradiated.

The bandwidth of the amplifier shall be sufficiently large to ensure that the overall noise bandwidth is determined by F.

The measuring circuit shall be electrically grounded and shielded so as to prevent spurious signals from interfering with the measurement of low level noise signals.

The effective (noise) bandwidth B of F shall be 15 % or less of its centre frequency.

d) Measurement procedure

Apply specified supply voltages and currents provided by P to the appropriate connections of D.

Increase the centre frequency of filter F from a very low value at which the noise voltage V_m is still decreasing with increasing frequency up to a value where V_m becomes nearly constant. See Figure 27 which shows V_m in decibels as a function of f. Note the value V_m^* at this frequency.

Decrease the frequency until V_m has increased by 3 dB (by a factor ≅ $\sqrt{2}$) compared to V_m*. This frequency is the corner frequency F_{cor}.

Decrease the frequency further and measure $V_m(f_m)$ at the specified frequency f_m which refers to a point in nearly linear region of the curve in Figure 27.

Calculate the low frequency output noise power (spectral) density as:

$$P_{no,\lambda,LF} = \frac{(V_m / G_v)^2}{R_L \times B}$$

NOTE The functions of the load resistor, filter, amplifier and r.m.s. noise voltage measuring instrument are typically incorporated in r.f. spectrum analyzer instruments. Such instruments can be used in place of the individual circuit elements shown in the circuit diagram. In that case, particular care should be paid to calibration of spectrum analyzers and to good impedance matching to D.

e) *Specified conditions*

- Ambient or case temperature (T_{amb} or T_{case}).
- Supply voltages and currents provided by P.
- Load resistance (R_L).
- Measuring frequency (f_m) for $P_{no,\lambda,LF}$.
- Effective bandwidth (B) of F.

Figure 27 shows the graph of V_m versus frequency.

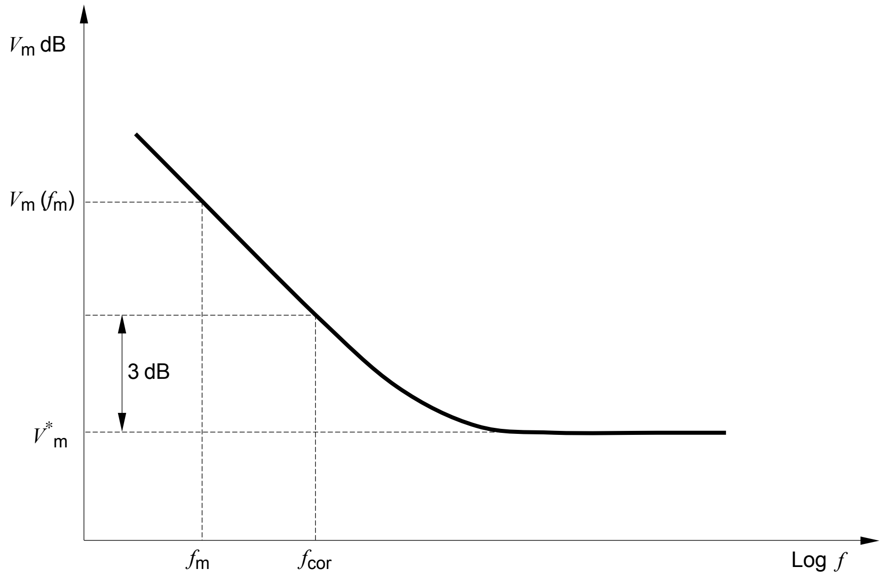


Figure 27 – Graph of V_m versus frequency

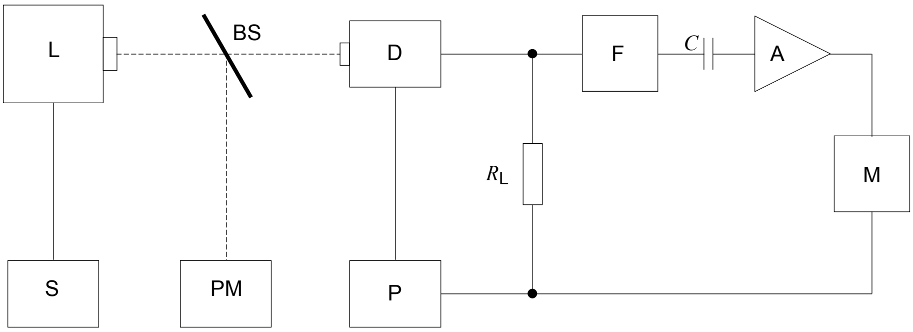
5.10 Minimum detectable power of PIN-TIA module

a) *Purpose*

To measure the minimum detectable power of a PIN-TIA module at a specified bit-error ratio (BER) or carrier-to-noise ratio (C/N).

b) *Circuit diagram*

Figure 28 shows the circuit diagram for measuring minimum detectable power of a PIN-TIA module at a specified bit-error rate (BER) or carrier-to-noise ratio (C/N).



Key

L	radiation source with adjustable d.c. and modulated radiant power (Φ_e, $\Delta\Phi_e$)
S	sinusoidal signal source (for analogue measurement) or signal source to generate appropriate digital signal under specified conditions (for digital measurement)
BS	beam splitter
PM	optical signal measuring instrument
D	device being measured
P	power supply to provide specified operating voltages and currents to D
R_L	load resistance
EQ	equalizer, if required
C	coupling capacitor
A	amplifier with centre frequency f_{mb} and bandwidth B (for analogue measurement) or amplifier with variable gain (for digital measurement)
M	r.m.s. voltage meter (for analogue measurement) or bit-error rate counter (for digital measurement)

Figure 28 – Circuit diagram for measuring minimum detectable power of a PIN-TIA module at a specified bit-error rate (*BER*) or carrier-to-noise ratio (*C/N*)

c) *Precautions to be observed*

Optical power on PM shall be calibrated so that the a.c. irradiated power on the optical port of D can be measured.

The C/N of L shall be high enough to avoid the increase in the detected noise.

Only the optical port of D shall be irradiated.

d) *Measurement procedure*

Apply specified supply voltages generated by P to D and modulate L by S under the condition of sufficient high extinction ratio.

Adjust the radiant power measured on PM to obtain the specified bit-error rate maintaining the constant extinction ratio of L and appropriate input condition of M by adjusting the gain of A.

Measure the radiant power on PM. This is the minimum detectable power of D.

e) *Specified conditions*

- Ambient or case temperature (T_{amb} or T_{case}).
- Supply voltages of D.
- Peak emission wavelength and spectral radiation bandwidth of L (λ_p, $\Delta\lambda$).
- Signal bit-rate.
- Modulation scheme (RZ or NRZ).
- Bit-error rate.
- Signal pattern (bit sequence and mark density).
- Equalizer parameters, if required.

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